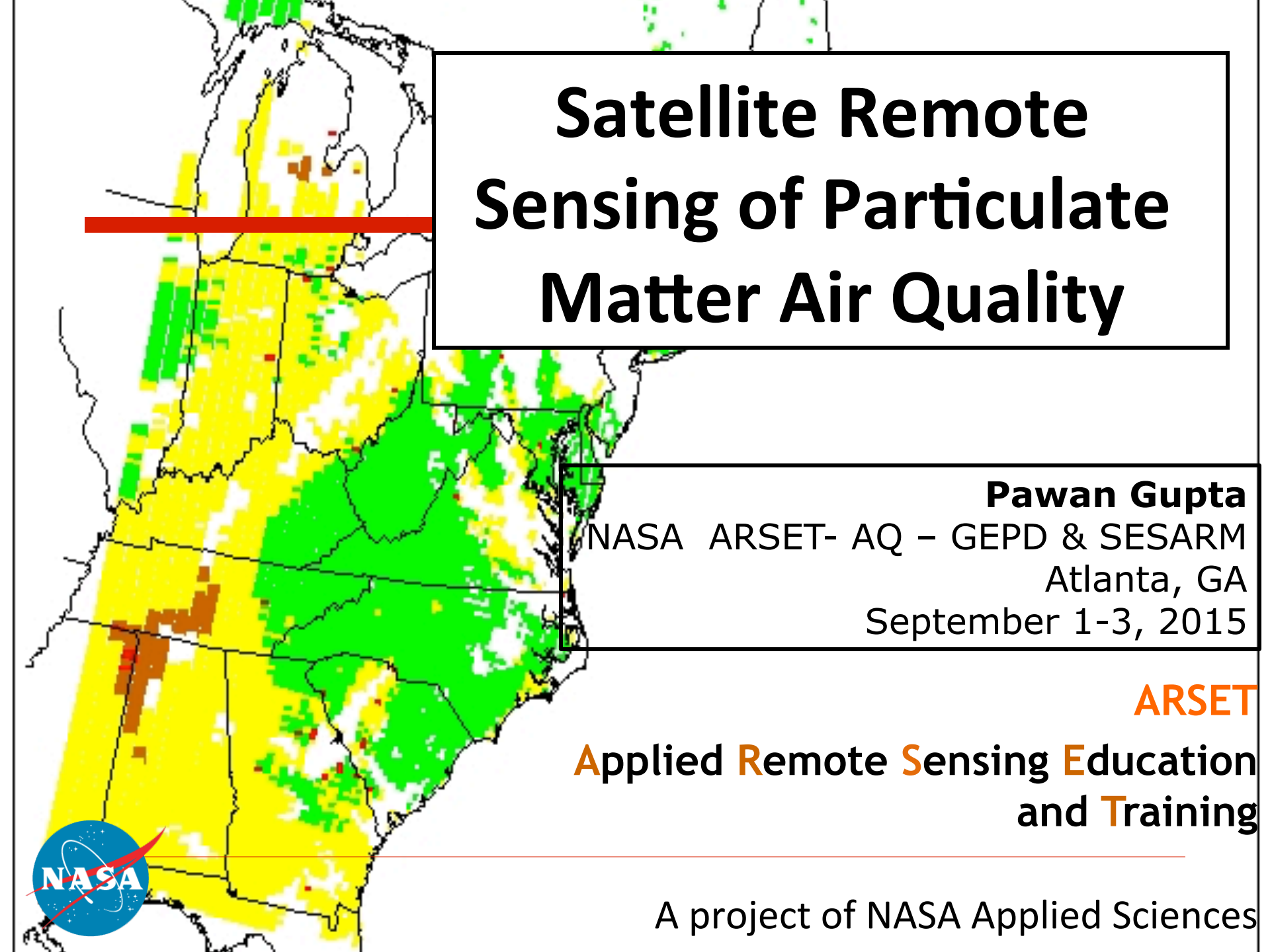


Satellite Remote Sensing of Particulate Matter Air Quality

Pawan Gupta
NASA ARSET- AQ – GEPD & SESARM
Atlanta, GA
September 1-3, 2015

ARSET

Applied Remote Sensing Education and Training

A project of NASA Applied Sciences

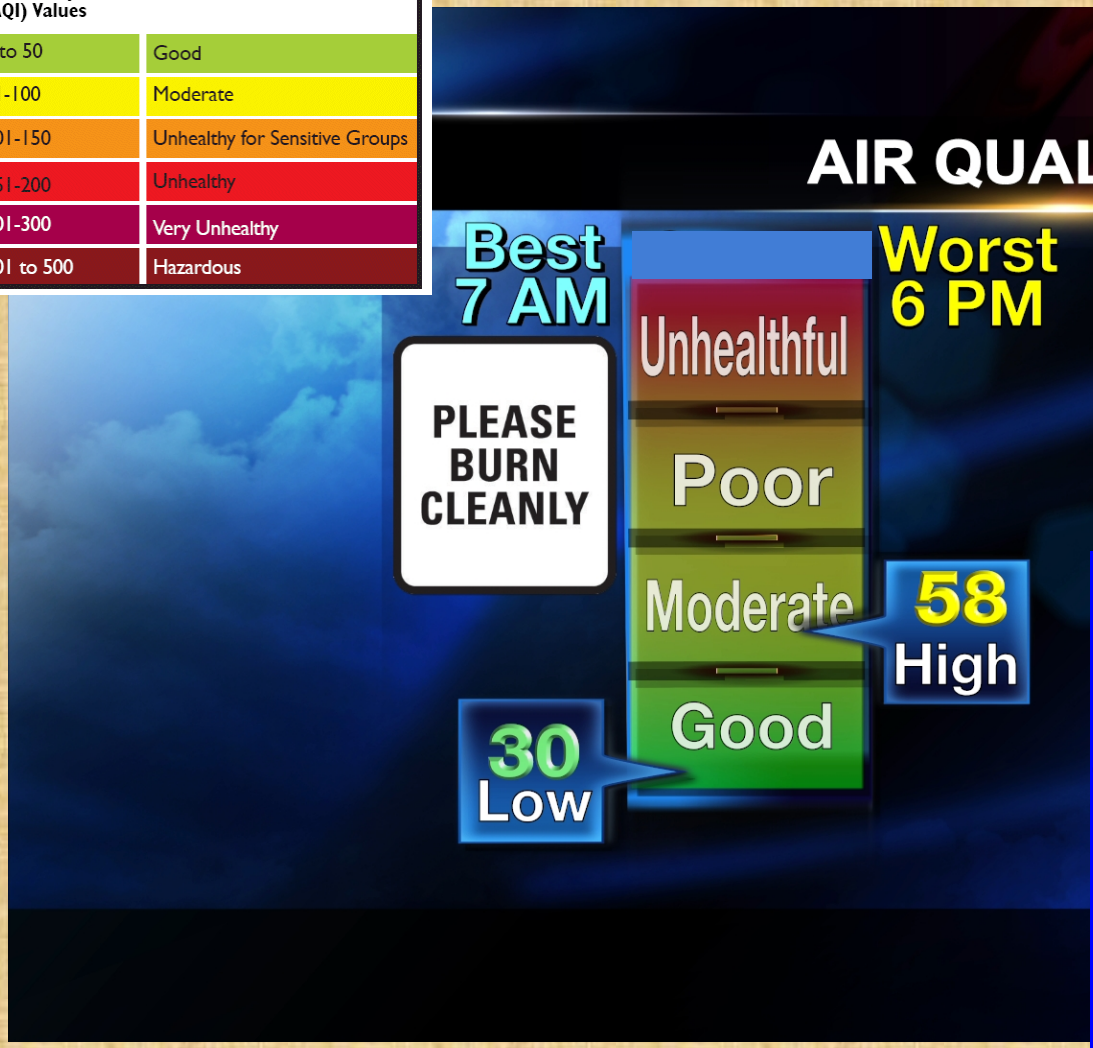
OBJECTIVE

Estimation of PM2.5 mass concentration at surface (μgm^{-3}) while utilizing satellite derived Aerosol Optical Depth (AOD – unit less quantity) at visible wavelength

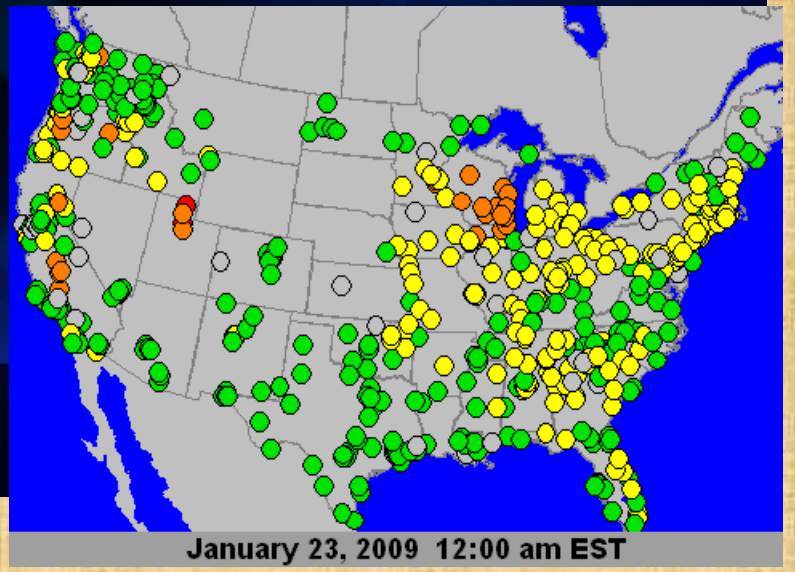
What are we looking for ? & Why ?

AIR QUALITY INDEX

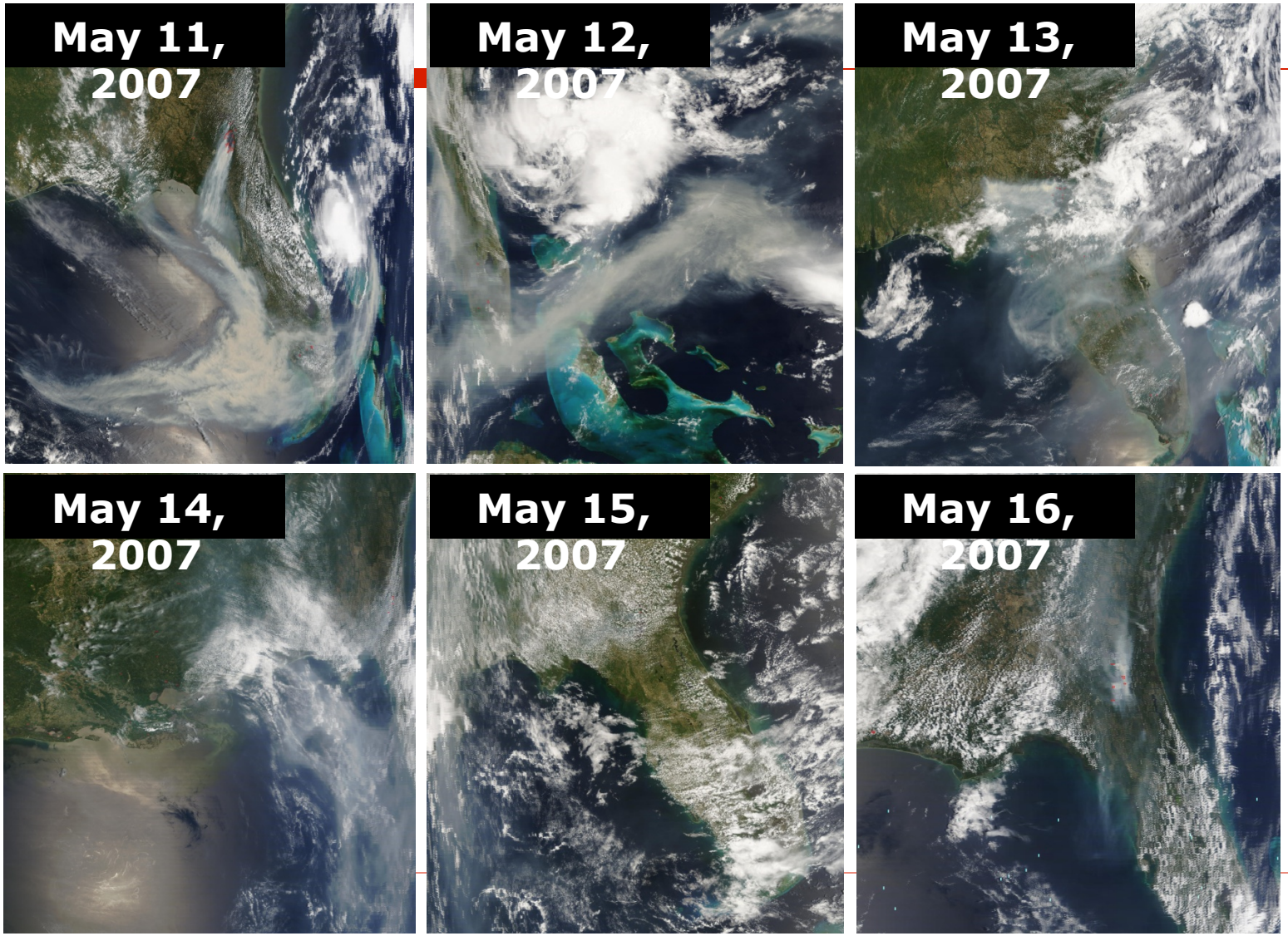
Air Quality Index (AQI) Values	Levels of Health Concern
0 to 50	Good
51-100	Moderate
101-150	Unhealthy for Sensitive Groups
151-200	Unhealthy
201-300	Very Unhealthy
301 to 500	Hazardous



Spatial Gaps

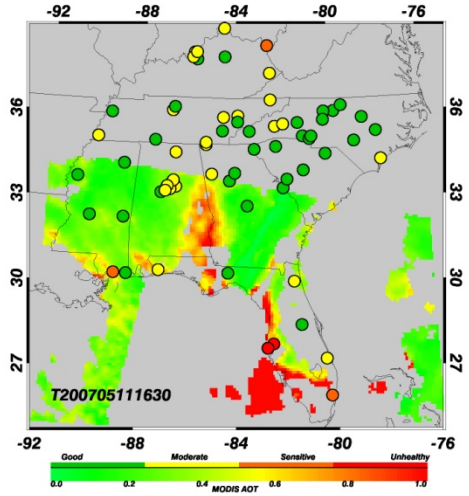


MODIS-Terra True Color Images

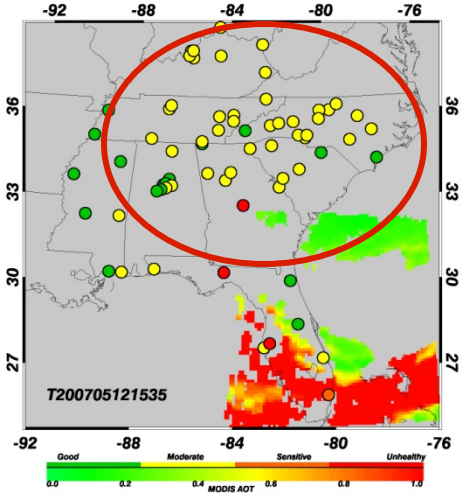


MODIS-Terra Aerosol Optical Thickness

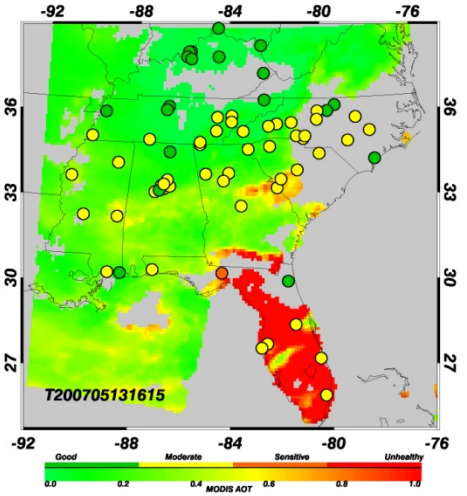
May 11, 2007



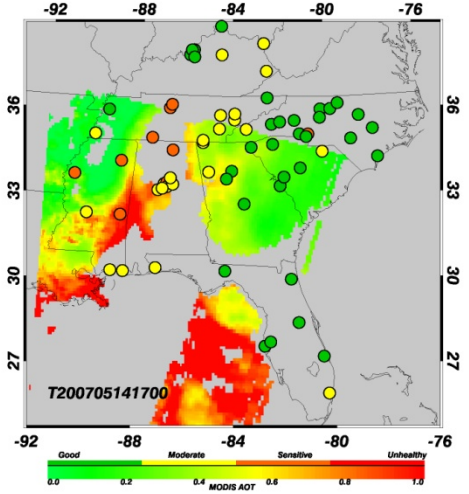
May 12, 2007



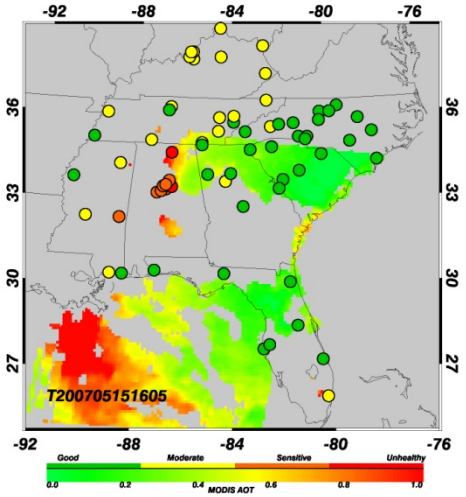
May 13, 2007



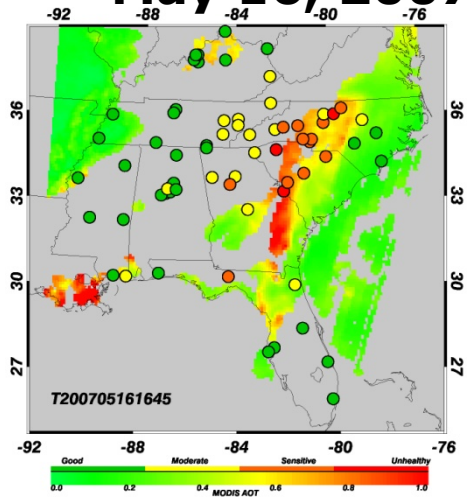
May 14, 2007

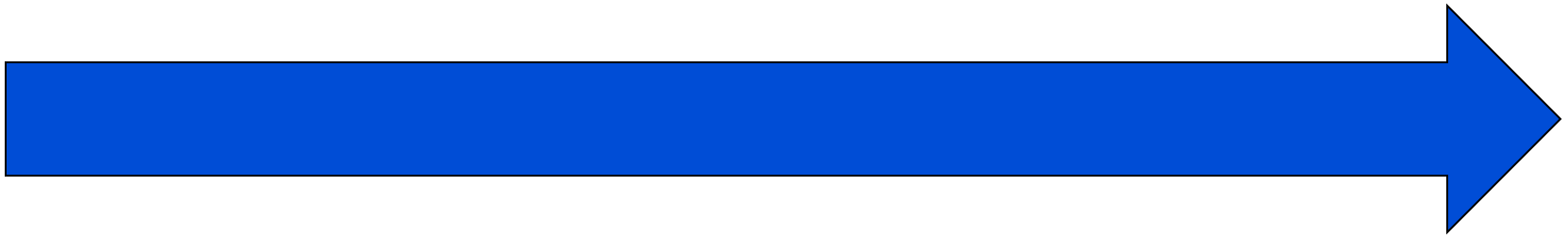


May 15, 2007



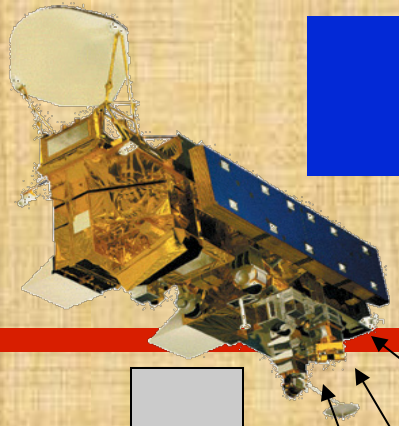
May 16, 2007





AOD (or AOT) to PM

What Satellite Provides?



Satellite

Sun

Column Satellite Measurement

Seven MODIS bands are utilized to derive aerosol properties 0.47, 0.55, 0.65, 0.86, 1.24, 1.64, and 2.13 μm

Ozone

$$AOT(\tau) = \int \beta_{ext}\, dz$$

Rayleigh Scattering

10km

Particle size
Composition
Water uptake
Vertical Distribution

Water vapor + other gases (absorption)

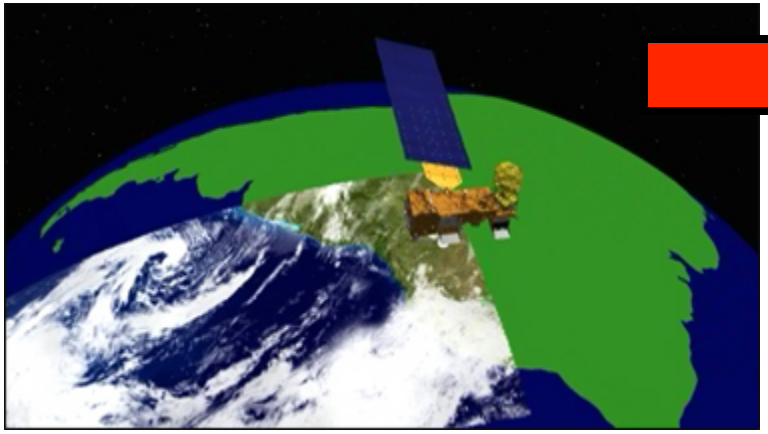
Aerosol

Surface

10X10 km² Res.

Satellite retrieval issues - inversion (e.g. aerosol model, background).

Measurement Technique

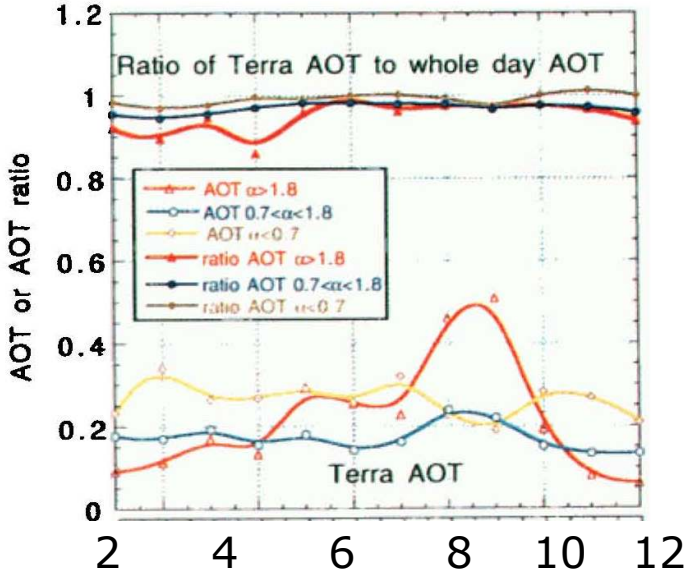


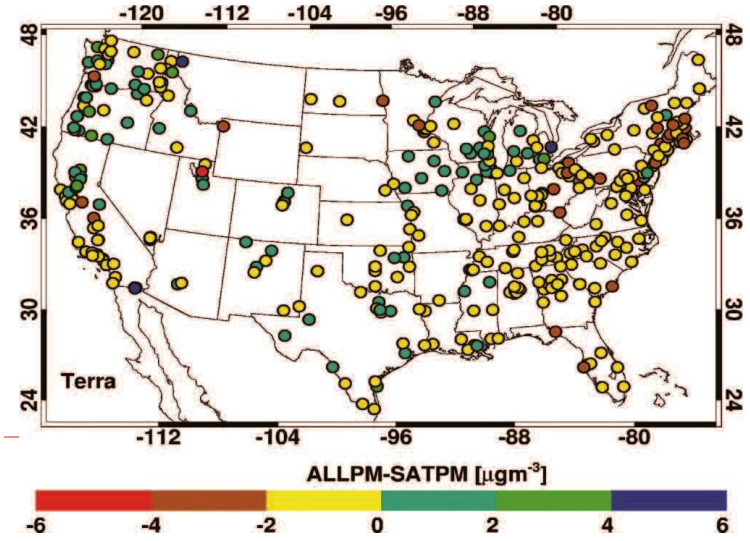
AOD – Column integrated value (top of the atmosphere to surface) - Optical measurement of aerosol loading – unit less. AOD is function of shape, size, type and number concentration of aerosols

PM2.5 – Mass per unit volume of aerosol particles less than 2.5 µm in aerodynamic diameter at surface (measurement height) level

Support for AOD-$PM_{2.5}$ Linkage

- Current satellite AOD is sensitive to $PM_{2.5}$ (Kahn et al. 1998)
- Polar-orbiting satellites can represent at least daytime average aerosol loadings (Kaufman et al., 2000)
- Missing data due to cloud cover appear random in general (Christopher and Gupta, 2010)





AOD – PM Relation

$$AOD(\lambda) = \int_{0}^{\text{Top-of-Atmosphere}} \beta_{ext,p}(\lambda, z)\,dz$$

surface

$$C = \frac{4\rho r_e}{3Q} \times \frac{f_{PBL}}{H_{PBL}} \times AOD$$

- ρ – particle density
- Q – extinction coefficient

} **Composition**

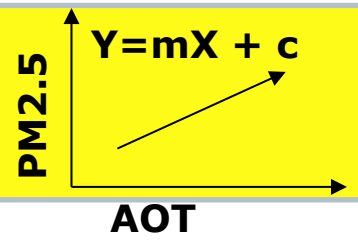
- r_e – effective radius ⟹ **Size distribution**
- f_{PBL} – % AOD in PBL
- H_{PBL} – mixing height

} **Vertical profile**

PM2.5 Estimation: Popular Methods

Difficulty Level

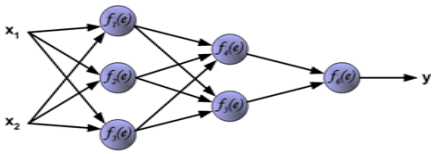
Two Variable Method



Multi-Variable Method

$$PM2.5 = \beta_0 + \alpha * \tau + \sum_{n=1}^{m} (\beta_n * M_n)$$

Artificial Intelligence



MSC

$$Estimated\ PM_{2.5} = \frac{Model\ surface\ aerosol\ concentration}{Model\ AOD} \times Retrieved\ AOD$$

and Empirical Methods, Data Assimilation etc. are under utilized

Simple Models from Early Days

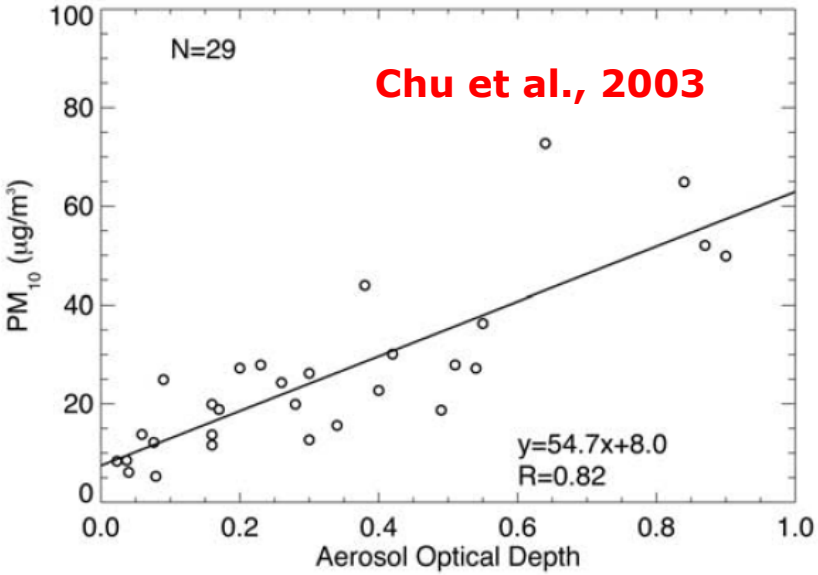
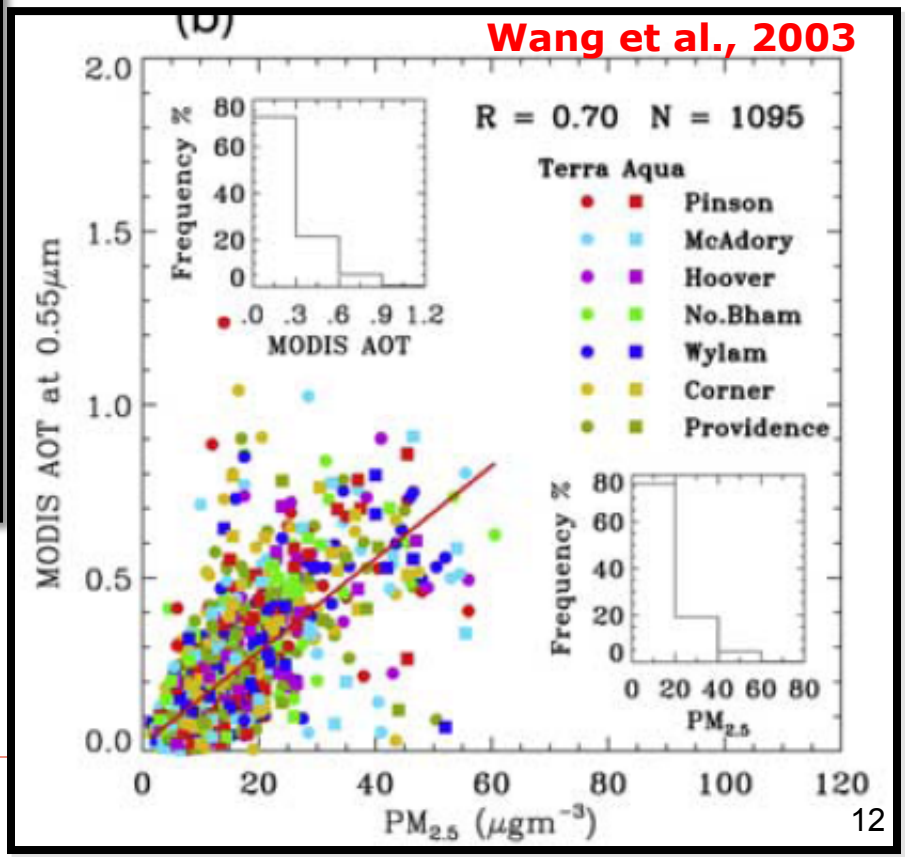
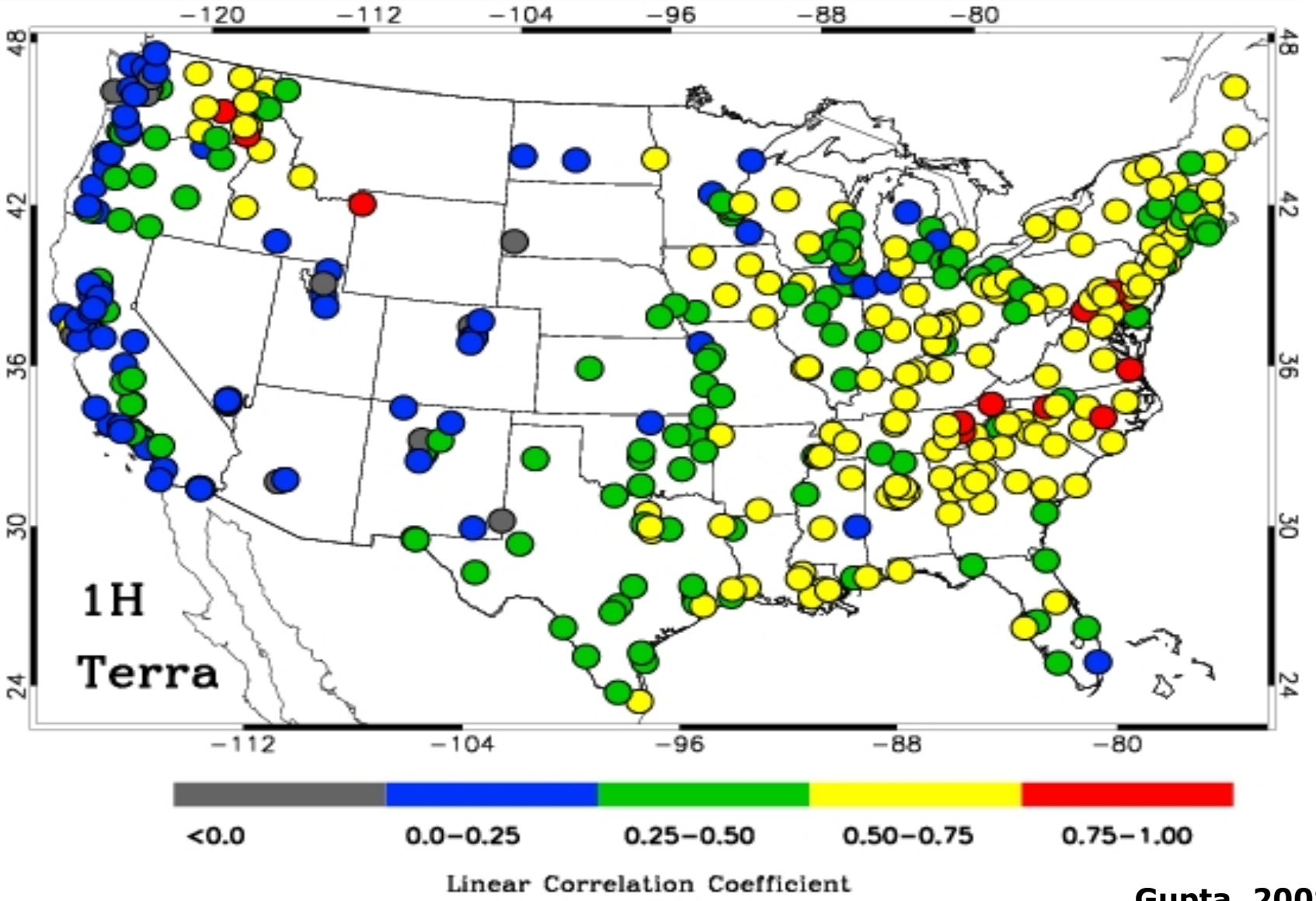


Figure 14. Relationship between 24-hour PM_{10} concentrations and daily averaged AERONET τ_a measurements from August to October 2000 in northern Italy.



AOT-PM2.5 Relationship

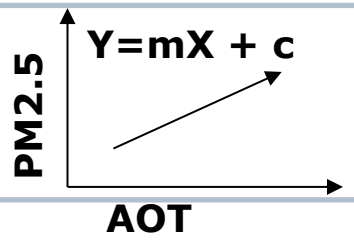


Gupta, 2008

PM2.5 Estimation: Popular Methods

Difficulty Level

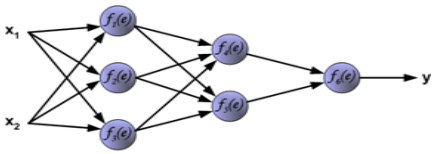
Two Variable Method



Multi-Variable Method

$$PM2.5 = \beta_0 + \alpha * \tau + \sum_{n=1}^{m} (\beta_n * M_n)$$

Artificial Neural Network



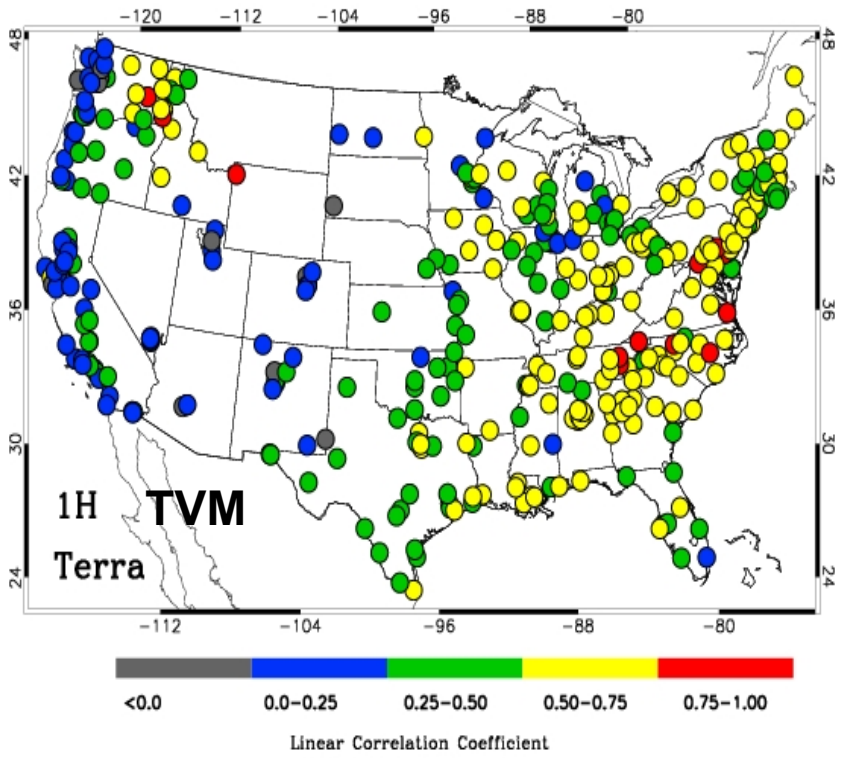
MSC

$$Estimated\ PM_{2.5} = \frac{Model\ surface\ aerosol\ concentration}{Model\ AOD} \times Retrieved\ AOD$$

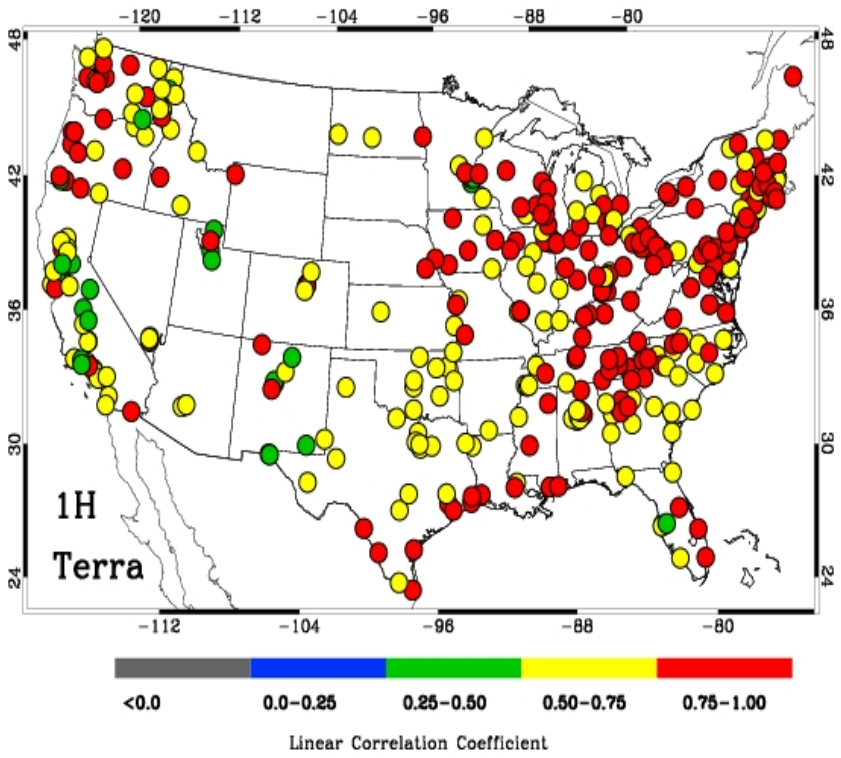
and Empirical Methods, Data Assimilation etc. are under utilized

Multi Variable Method

Predictor: AOD



Predictor: AOD + Meteorology

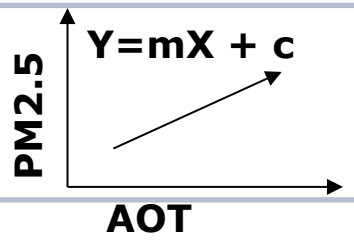


Linear Correlation Coefficient between observed and estimated PM2.5 Gupta, 2008

PM2.5 Estimation: Popular Methods

Difficulty Level

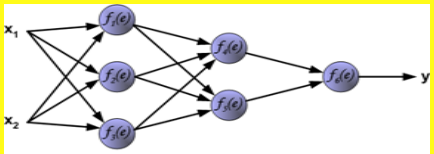
Two Variable Method



Multi-Variable Method

$$PM2.5 = \beta_0 + \alpha * \tau + \sum_{n=1}^{m} (\beta_n * M_n)$$

Artificial Neural Network

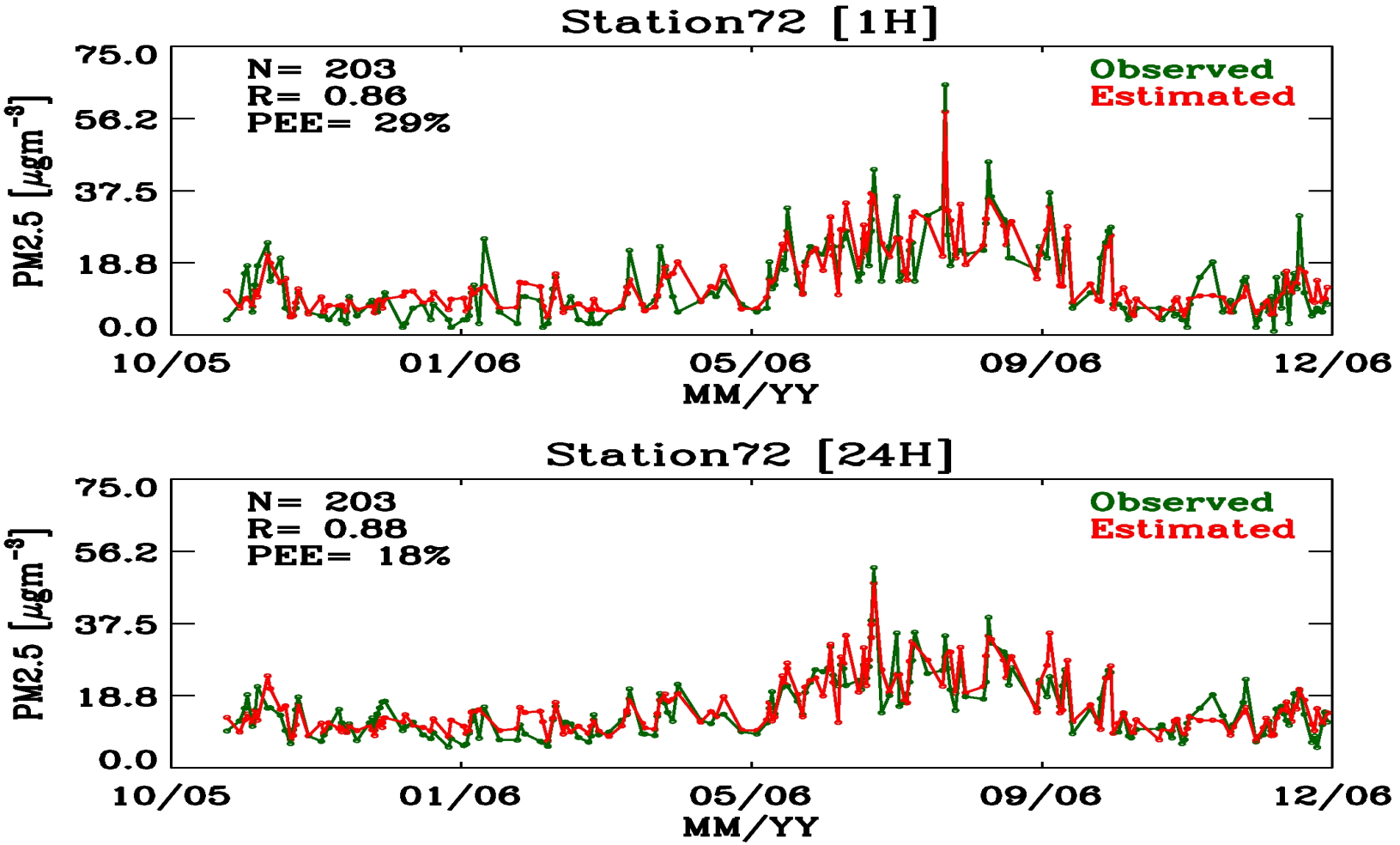


MSC

$$Estimated\ PM_{2.5} = \frac{Model\ surface\ aerosol\ concentration}{Model\ AOD} \times Retrieved\ AOD$$

and Empirical Methods, Data Assimilation etc. are under utilized

Time Series Examples of Results from ANN



Gupta et al., 2009

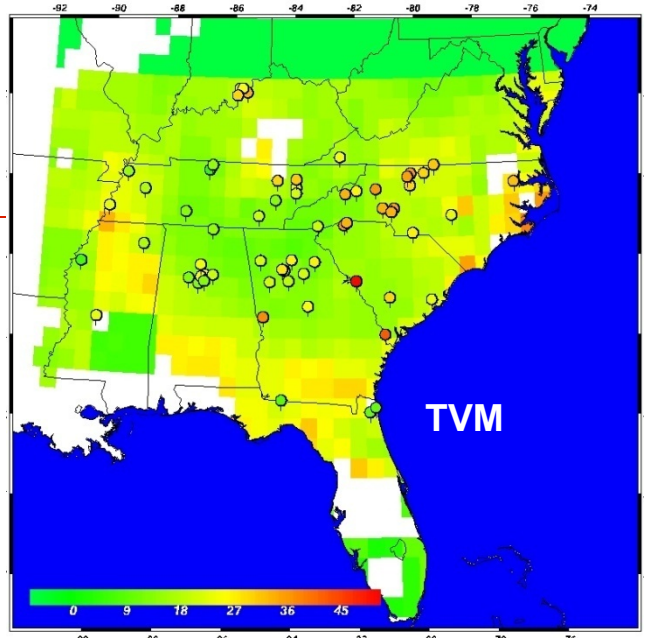
TVM

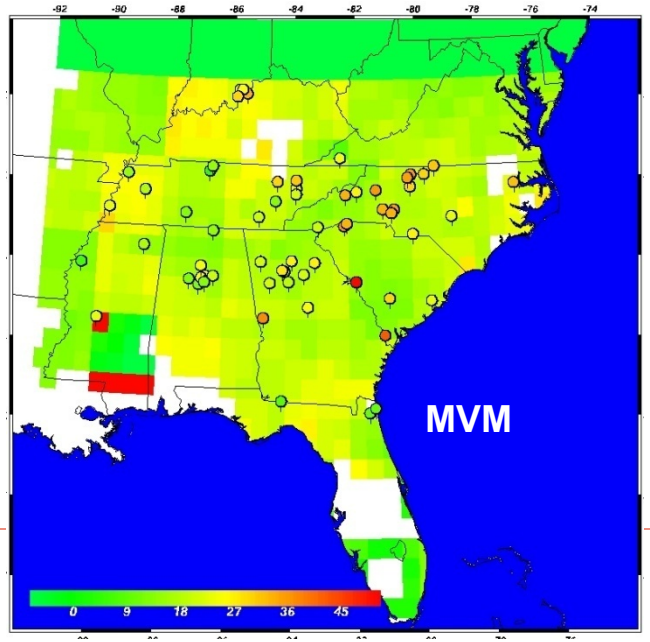
Vs

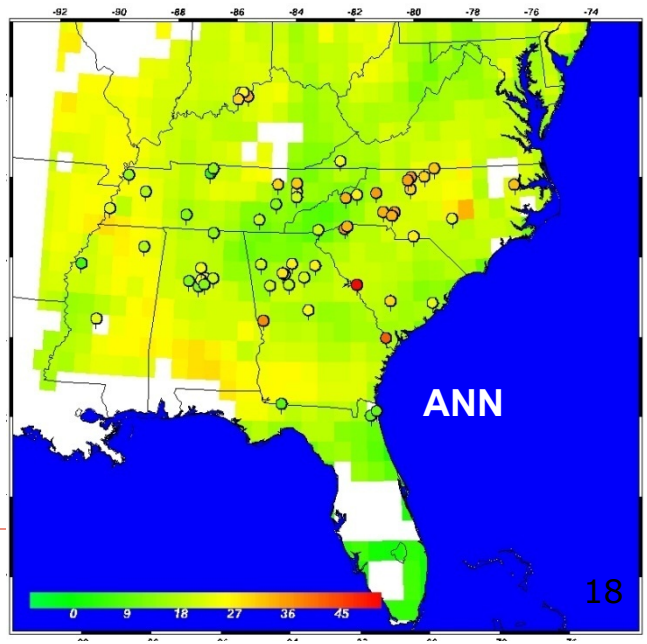
MVM

vs

Artificial Intelligence





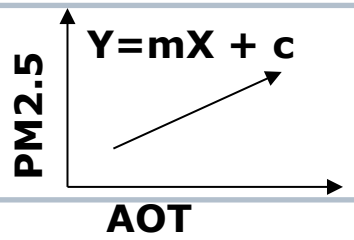


Gupta et al., 2009

PM2.5 Estimation: Popular Methods

Difficulty Level

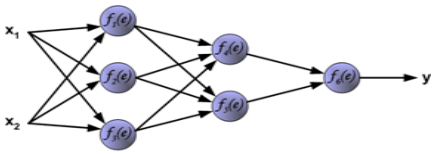
Two Variable Method



Multi-Variable Method

$$PM2.5 = \beta_0 + \alpha * \tau + \sum_{n=1}^{m} (\beta_n * M_n)$$

Artificial Neural Network



MSC

$$\text{Estimated } PM_{2.5} = \frac{\text{Model surface aerosol concentration}}{\text{Model AOD}} \times \text{Retrieved AOD}$$

and Empirical Methods, Data Assimilation etc. are under utilized

Scaling approach

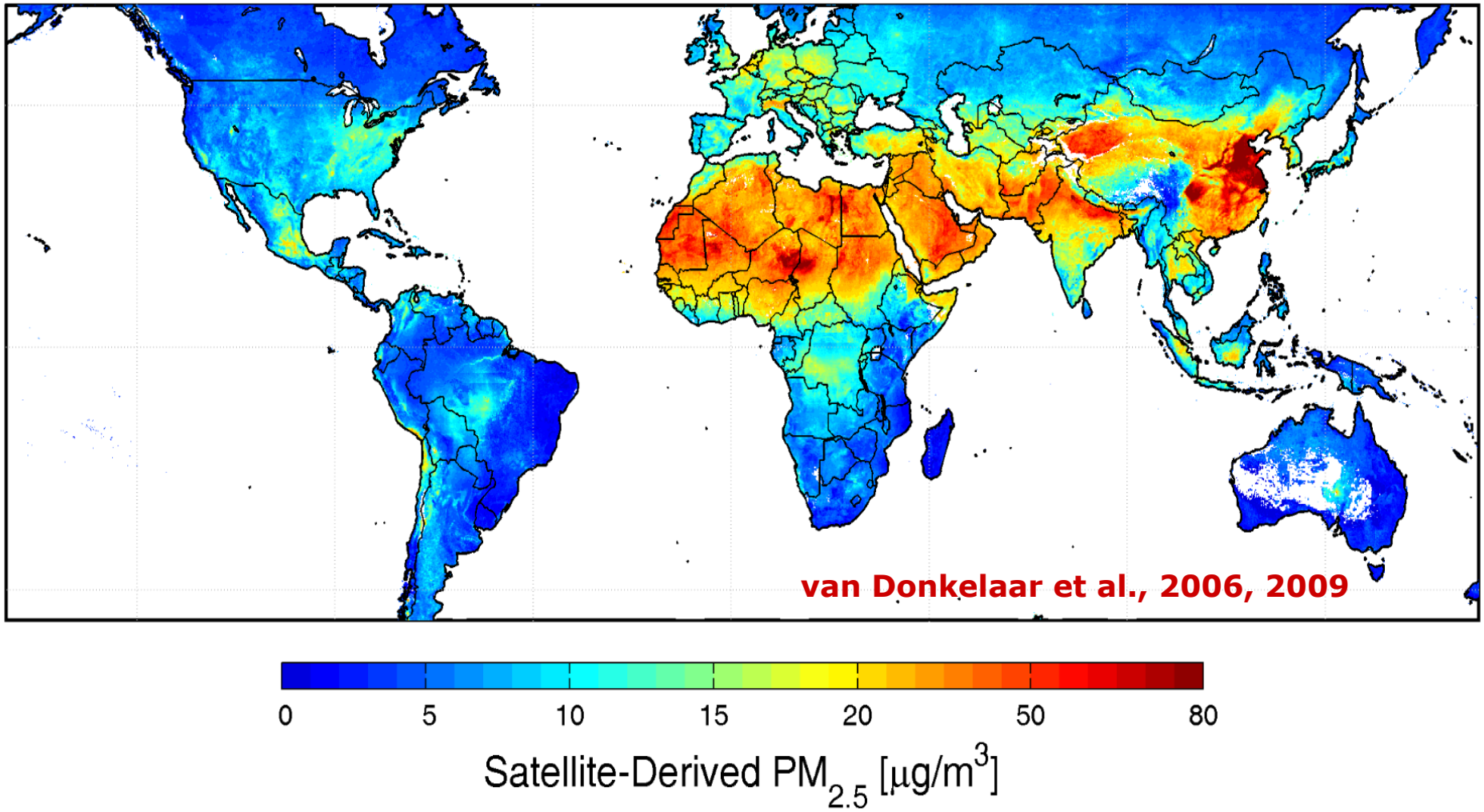
- Basic idea: let an atmospheric chemistry model decide the conversion from AOD to $PM_{2.5}$. Satellite AOD is used to calibrate the absolute value of the model-generated conversion ratio.

Satellite-derived $PM_{2.5}$ =

$$\left(\frac{PM_{2.5}}{AOD}\right)_{Model} \text{ x satellite AOD}$$

Liu et al., 2006,

Annual Mean PM2.5 from Satellite Observations



Questions to Ask: Issues

- ✓How accurate are these estimates ?
- ✓Is the PM2.5-AOD relationship always linear?
- ✓How does AOD retrieval uncertainty affect estimation of air quality
- ✓Does this relationship change in space and time?
- ✓Does this relationship change with aerosol type?
- ✓How does meteorology drive this relationship?

The Use of Satellite Data

- Currently for research
  - Spatial trends of $PM_{2.5}$ at regional to national level
  - Interannual variability of $PM_{2.5}$
  - Model calibration / validation
  - Exposure assessment for health effect studies
- In the near future for research
  - Spatial trends at urban scale
  - Improved coverage and accuracy
  - Fused statistical – deterministic models
- For regulation?

Trade-offs and Limitations

- Spatial resolution – varies from sensor to sensor and parameter to parameter
- Temporal resolution – depends on satellite orbits (polar vs geostationary), swath width etc.
- Retrieval accuracies – varies with sensors and regions
- Calibration
- Data Format, Data version
- Etc.

Assumption for Quantitative Analysis

When most particles are concentrated and well mixed in the boundary layer, satellite AOD contains a strong signal of ground-level particle concentrations.

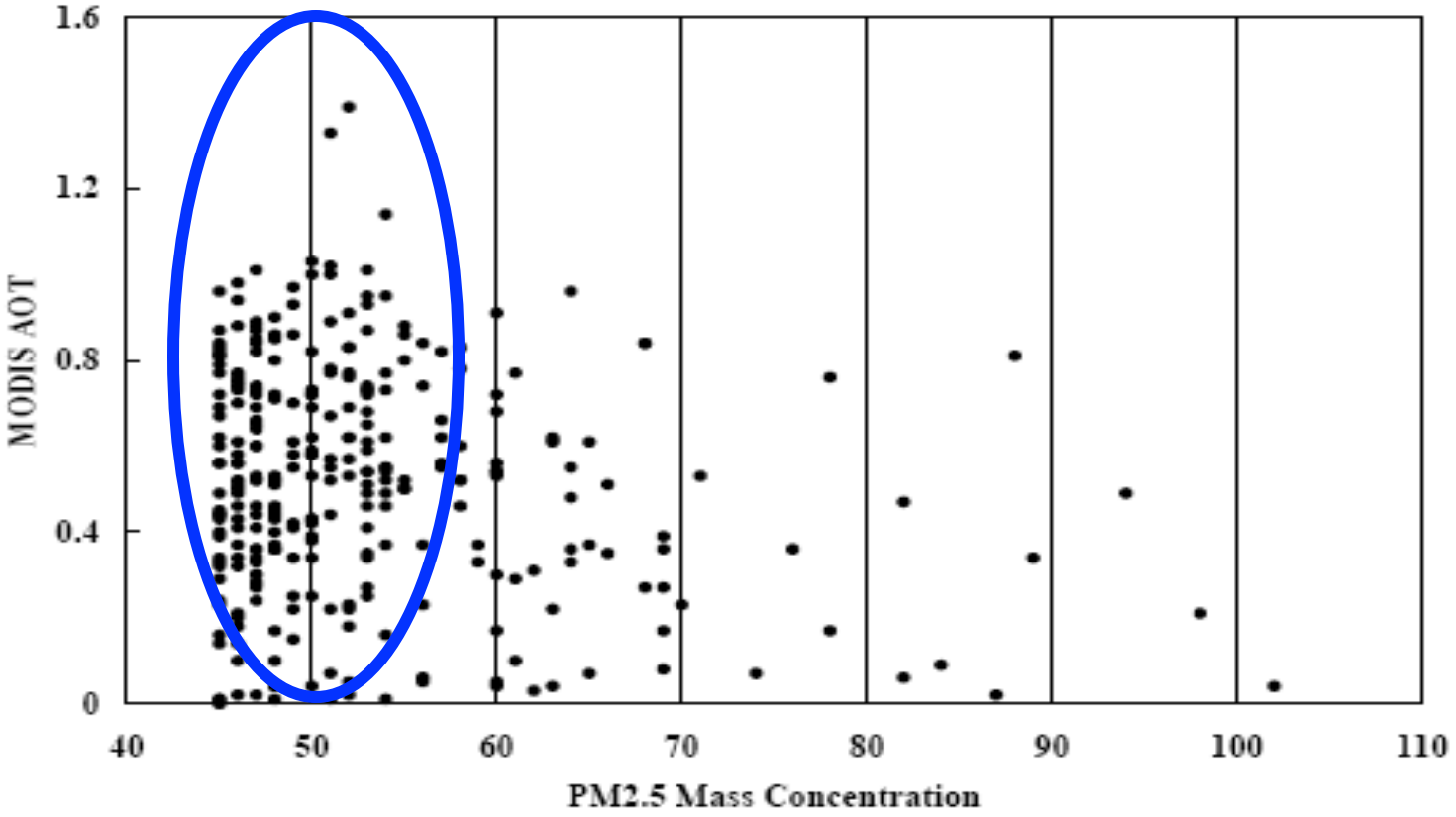
No textbook solution!

Shopping List - Requirements for this job

- A good high speed computer system
- Internet to access satellite & other data
- Some statistical software (SAS, R, Matlab, etc., IDL, Fortran, Python, etc.)
- Some programming skill
- Knowledge of regional air pollution patterns
- Ideally, GIS software and working knowledge

- Surface & Satellite Data

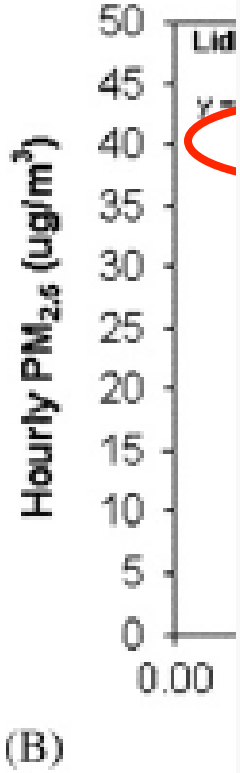
Limitation: Vertical Distribution of Aerosols

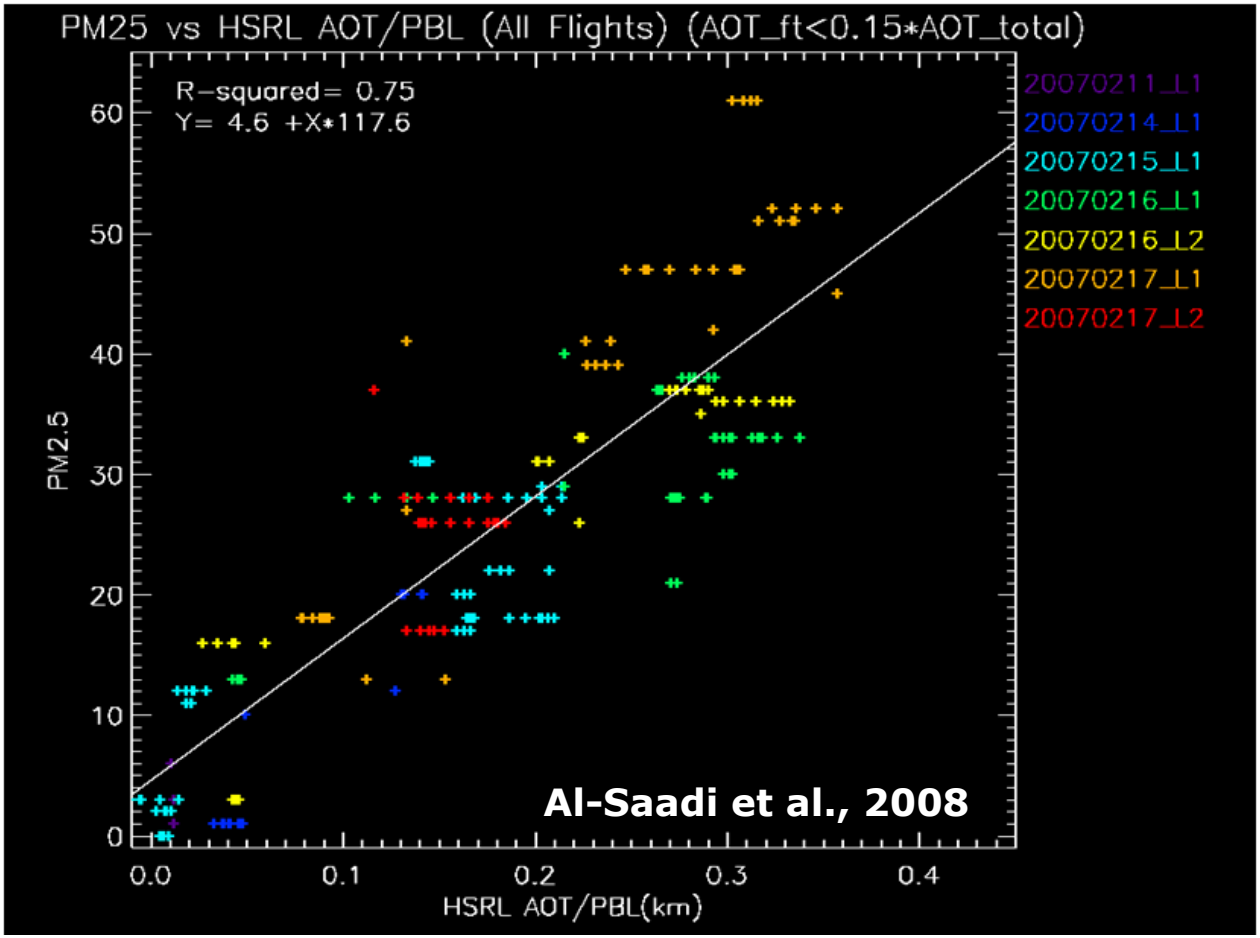


Vertical Distribution

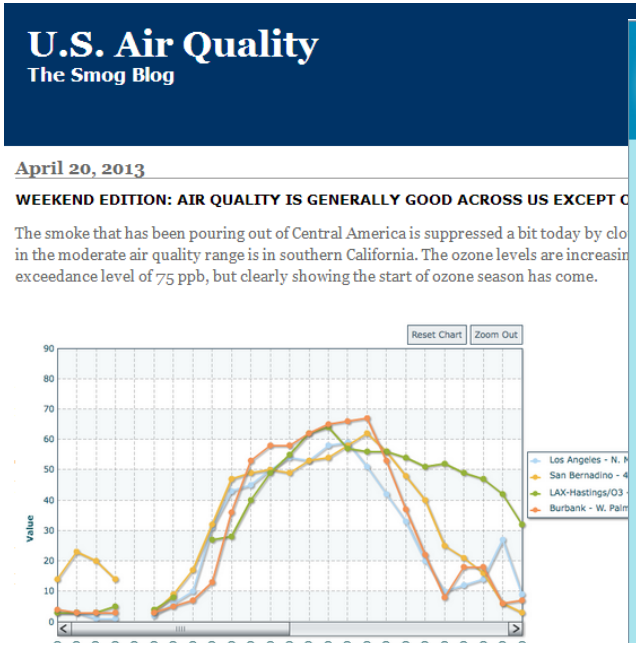
Correlation of Surface PM2.5 with HSRL AOD / PBL, All Flights

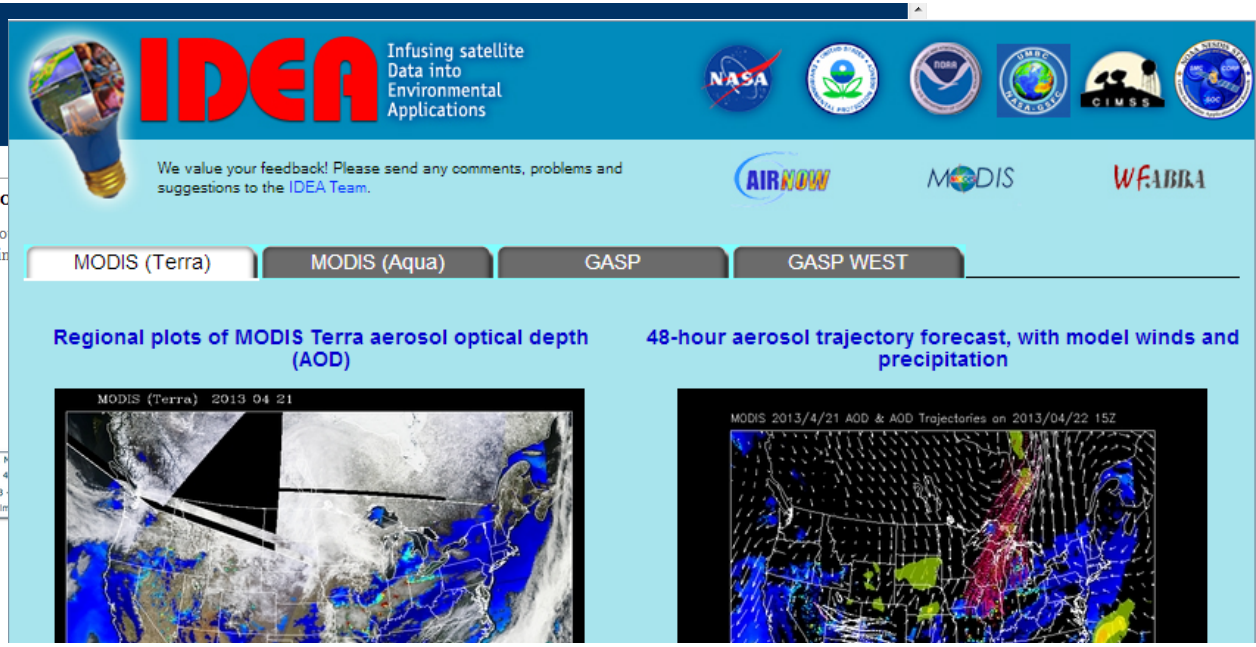
- Normalizing AOD with boundary layer height significantly improves correlation with $PM_{2.5}$ (R^2 increases from 0.36 to 0.75)
- With accurate estimates of PBL height, AOD can be good proxy for $PM_{2.5}$





Some online tools

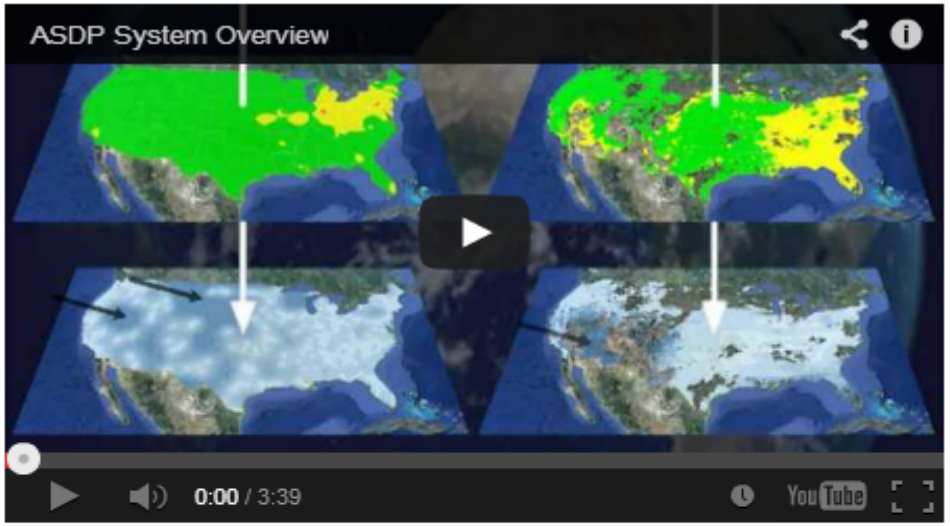




The AIRNow Satellite Data Processor (ASDP)

is a system under development that enables blending (or fusing) of surface $PM_{2.5}$ measurements and satellite-estimated $PM_{2.5}$ concentrations to provide additional air quality information to AIRNow in regions without existing surface air quality monitoring networks.

The ASDP system builds the capacity and framework necessary to implement satellite data as these data become available to the air quality community. This project is being funded by the NASA Applied Sciences Program.



Log In to Learn More

2009 CRITICAL REVIEW

ISSN:1047-3289 J. Air & Waste
DOI:10.3155/1047-3289.59.6.
Copyright 2009 Air & Waste Manage


R.M. Hoff S.A. Christopher

Remote Sensing of Particulate Pollution
from Space: Ha
Promised Land

Raymond M. Hoff
Department of Physics and the Joint Center for Earth Systems Tec
and Technology Center, University of Maryland
th Sciences

Sundar A.

IMPLICATIONS

Satellite measurements are going to be an integral part of the Global Earth Observing System of Systems. Satellite measurements by themselves have a role in air quality studies but cannot stand alone as an observing system. Data assimilation of satellite and ground-based measurements into forecast models has synergy that aids all of these air quality tools.

The use of the AOD as a measure for mass concentration has skill in some regions but less in others and does not provide a uniform way to measure aerosols across the United States. We discussed in Table 4 the range of mea-

dards (NAAQS).[142] The 39-yr history of those standards parallels the time period that satellite meteorology and observations have developed and yet, to date, no satellite measurements have been used to quantitatively address the NAAQS. From the review conducted here, only one congres-

EPA has taken a satellite observations role for itself in the Exceptional Events Rule.[144] If a region can show conclusively that they are being impacted by an event (a fire, a dust storm, etc.) that is outside of their jurisdiction to regulate, the event can be flagged as a nonexceedance event. This provides a significant motivation for regional

ellite data possible in significant exceedances only. Applications such as event identification, transport, and atmospheric composition determination are strengths of satellite measurements. Where high precision is required (compliance monitoring, the "but for" test, and quantitative measurement of visibility effects on Class I areas), satellite data are presently of limited utility.

Although the desire for the use of satellite data for air quality purposes is widely stated, the reality is that many of the measurements have not yet met the promise that they can be operationally used for today's air quality monitoring requirements. Precision in measuring AOD is

Suggested Reading